

# Rome Metro – where engineering meets art

Rome's Metro Line C is a fascinating project on many levels. As the two TBMs mining the latest section were preparing to pass by the city's famed Colosseum, Kristina Smith took a tour round site.

One of the first signs of the tunnelling works underway beneath the centre of Rome are the huge metal braces supporting some of the city's historic monuments. The Aurelian Walls are braced either side with a system of shoring in two locations. Similar support is visible on the Church of Santa Maria in Dominica and the Pilot of Aqueduct Celimontano. There are others too.

Contractor Metro C, a consortium of companies led by Astaldi, is mining two 6.7m-diameter metro tunnels 35m below the surface using Herrenknecht EPB machines. When TJ visited site in early May, one of the two machines had stopped for a thorough health check, 350m before it would pass closest to the Colosseum at a distance of 15m in plan.

"We expect potential movements of a few millimetre," says Andrea Sciotti, director of operations for Roma Metropolitana, the organisation set up to manage the construction

of Line C on behalf of the City of Rome. "The Colosseum has been completely monitored with sensors for horizontal and vertical displacement and vibration since 2015."

This latest section of Line C consists of just two stations, Fori Imperiali and Amba Aradam, 3km of parallel tunnels and two shafts. Known as Section T3, it runs right under – and through – Rome's historical heart.

The technical and logistical challenges encountered here illustrate some of the difficulties the wider program of works has faced: the need to protect Rome's ancient monuments; hugely significant – and disruptive – archaeological finds; a variety of ground treatment; and changes to the design.

### Ambitious plans

When the Metro C consortium won the contract for Line C back in early 2006, it offered both the lowest bid and the shortest potential programme. Its bid price was €2.17bn compared to the

tender estimate of €2.5bn and there was talk of the whole line being commissioned early in 2013, rather than in 2015 as expected.

The earliest ambition for Line C was that it would cross the city from the northwest to the southeast with almost 40 stations. Intersecting twice with the existing metro Line A and once with Line B, it would reduce congestion in the city centre and improve air quality and passenger journeys. The line is Rome's first driverless one and features technology such as platform screen doors.

Metro C's package of works encompassed six sections of line – T2 through to T7 (see Figure 1) and 30 stations, 19 underground. The original plan envisaged sections T4 and T5 opening first, followed by the remaining sections, although the sequence has been revised over the course of the programme.

Sections T7 and T6a, running from Monte Compatri in the southeast up to Parco di Centocelle opened first, in November 2014. The second section – T5 and most of T4 – from Parco di Centocelle to Lodi opened in June 2015. And San Giovanni station, the first interchange with Line A, opened in May 2018.

Currently section T3 is expected to be open by 2021, according to Sciotti. To date, funding for the line only as far as Fori Imperiali, the station close to the Colosseum has been secured, with design up to Venezia Station given the go-ahead. Metro C has submitted project finance proposals for a further section. As for Section T1, which was never part of Metro C's works, that has been on hold for a long time.

According to Sciotti, the cost for the line so far to Fori Imperiali will be €3bn, €800m of which will be spent on Section T3. Sciotti suggests that some of the reasons for the price escalation compared to the time of contract award include archaeological problems

Rome's Line C is operational as far as San Giovanni. The stretch from there to Fori Imperiali is now under construction.



and changes to the standard covering seismic design.

Both San Giovanni and Amba Aradam stations, which is currently under construction as part of T3, have been moved to a greater depth and the alignment of tunnels to and from them changed accordingly since the early designs. This is because the archaeological layer of ground, containing multiple artefacts from Rome's long history, was found to be deeper than expected here.

These two stations have also been redesigned so that they can double as museums. San Giovanni, which is already open, features archaeological finds from multiple depths and periods of history in glass cases which are part of the station.

"San Giovanni gives the public the story of the site. We can take the train passing between the old strata. We can read the depth and historical age of different cultures, so we can read the story of the site from ground level to prehistoric age," explains Sciotti.

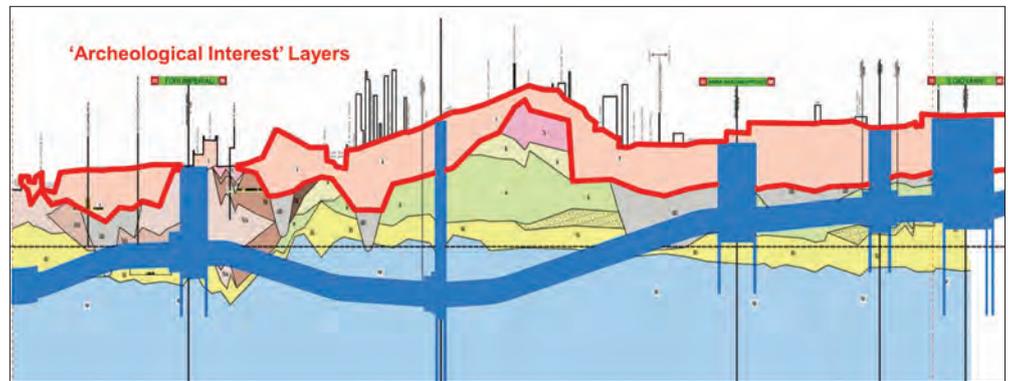
Amba Aradam station has moved location since the preliminary design. It was first placed in Largo dell-Ambra Aradam and is now in Piazzale Ipponio, a public garden. The revised design sees the whole station contained in one box, rather than two boxes linked by tunnels. The linked design became impossible when archaeologists vetoed the use of jet grouting because it could damage underground artefacts.

Ironically, the new position was assessed to have lower archaeological risk, but once excavations were underway this location revealed perhaps the most exciting finds of the whole route.

### Archaeological surprises

Metro C began construction of the T3 section in 2013, with the construction of Ambra Aradam Station and shaft 3.3, which lies between San Giovanni and Ambra Aradam stations. It began work on the second shaft, 3.2, between Ambra Aradam and Fori Imperiali stations and then excavation for the station subsequently.

The water table in this area is 6 or 7m below ground level, leading to a water pressure of



around 2.5 bar at the bottom of the excavations. Both the station boxes, which are formed with diaphragm walls, and the shafts have been waterproofed. Shaft 3.3 will provide space for a crossover as well as access for maintenance and emergencies while shaft 3.2 will be a ventilation shaft.

"If there is trouble during operation of the train, the system is designed to automatically take the train to the nearest station and the ventilation system starts to push the smoke and the heat in the opposite direction," says Sciotti.

The stretch of tunnel between shaft 3.3 and San Giovanni station was constructed using traditional methods rather than by TBM. "We did a 3.3m micro tunnel first, did radial injections to increase the strength of the ground and then enlarged the tunnel," explains engineer Daniele Ricci, who works for Roma Metropolitane and is responsible for the civil works.

The two TBMs, Herrenknecht machines which have been busy building Line C since 2009, started boring in 2018 having been refurbished. The stretch between shaft 3.3 and Amba Aradam was mucked with trains. From Amba Aradam onwards conveyors,

supplied by H+E, have brought the muck out.

As well as the visible above-ground support to some of Rome's historic buildings and structures, various sections of ground treatment have been deployed along different parts of the T3 section. Where the tunnels pass under the Aurelian Walls, which were built in the 3rd century to protect Rome against attacks, compensation grouting has been used to firm up the ground beneath the structures. The protection measures were successful, reports Sciotti, with around 5mm of settlement and no damage to the walls.

Compensation grouting will also be used where Line C underpasses the Colosseo Station for Line B. Originally, the plan was for Line A to link directly into this station, with a new section of station constructed directly under the existing one. However, this design was rejected for two reasons, says Sciotti.

First it would have caused extended disruption to Line B. And second, the new site for the station does not have any risk or archaeological discoveries. "In ancient times, there was a little hill in this area, the Velian

Section T3 of Rome's metro Line C runs through the historical heart of the city.

The depth of San Giovanni and Amba Aradam stations were lowered to avoid the layer of archaeological interest, shown here in red.

Hill, which was removed around 1930,” explains Sciotti. So, the Fori Imperiali station will be 50 or 60m from the existing Colosseo one, with the two stations connected by a foot tunnel.

Excavations for the station box for Amba Aradam station have revealed impressive archaeological finds. In March 2016, a 900 sq m barracks dating back to the time of the Emperor Hadrian in the 2nd Century AD were uncovered. This was followed by the further discovery of a luxurious villa belonging to a Roman military commander.

The barracks, found 9m below ground level, includes 39 rooms off a long corridor and a central fountain. Some of the well-preserved elements of the buildings included a mosaic floor, marble floors and wall frescos. There was also a grave alongside the barracks containing 13 adult skeletons.

While this discovery is exciting for archaeologists, residents and visitors to Rome, for the contractor it means that the pace of excavation had to decrease to a crawl. The method for excavation has all been set down in an ‘Archaeological Handbook’ which was created after the first part of the line had been built.

Metro C used a method called ‘modified-top-down’ which it had created at San Giovanni station where 4,000 artefacts were exposed during construction. This involves excavating down in 3m layers and creating slabs between the diaphragm walls using self-supporting prefabricated segments to avoid casting onto the earth.

“All the archaeological interest layers must be excavated with archaeological method of excavation, which involves many people and very low production, but we have to adapt for the respect of archaeological artefacts that we find during the excavation,” says Sciotti.

The parts of the barracks and villa, having been painstakingly excavated and removed will be stored and then reassembled in Amba Aradam station, partitioned off from the circulation spaces by glass screens. This element may not be ready when the line first opens.



### Controversy

Looking at the mainstream news stories relating to Line C, it seems that the technical challenges and achievements of the engineers and contractors are sometimes overshadowed by its public profile. One Rome resident, when asked what people think of the works, replied: “They think it is taking too long!”

It isn’t just the additional time that is annoying the public. There are the significant cost overruns. There have been suggestions of corruption amongst officials, with Rome’s public prosecutor carrying out a major investigation into an alleged fraud involving millions of Euros.

Metro C has said that the huge number of changes – by 2016 there had already been 45 major changes – has been a big contributor to the increase in cost. There are also numerous organisations and different levels of bureaucracy to navigate and all the archaeological and heritage interests on top of that.

Roma Metropolitana’s position as middle man, sitting between client the city of Rome, ATAC the operator and Metro C the contractor, must be a challenging one. When asked what the most challenging part of the works have been, Ricci sighs and says: “Everything I think.” Later he expands: “Technical problems, whether easy or difficult, we can solve them. The problem is when you have a lot of laws and different authorities in the same time and the same place.

“It’s also very difficult to understand which kind of artefact you will find buried in the ground. If you find special things it takes time to excavate. We did a lot of boreholes during investigation on the ground to understand what might be there, but it’s impossible to understand what is underground. Not just what you find, but the condition of what you find.”

Given the huge possibilities for unknown conditions and the potential for changes of scope, one has to question whether design and build is the most appropriate form of contract. When asked why this form of contract was chosen, Sciotti simply says: “Because the client thinks design and build is better for the allocation of the risk.”

It remains to be seen whether Line C will ever make it to the end of its originally proposed route at the Northeast corner of Rome. If it doesn’t, critics say it is massively over-designed, carrying just a fraction of the passenger numbers it was designed for.

The flip side of the argument is that the line is future-proofed, ready for its last section should funding become available and with the capacity to deal with changes in modes of transport across the capital in the future. The changes to station design to accommodate extravagant archaeological exhibitions may seem costly now, but there’s no denying that they will be an impressive addition to the city’s historical heritage. 

H+E conveyors in use on the Rome Metro Line C.